CONF-810704--2

LA-UR -81-813

TITLE: MODEL SIMPLIFICATION: A CASE STUDY OF END USE DEMAND MODELING IN THE TRANSPORTATION SECTOR

MASTER

AUTHOR(S): Andy Ford
Economics Group
Los Alamos National Laboratory

SUBMITTED TO: 1981 Summer Computer Simulation Conference, July 15-17, 1981, Washington, D.C.

DISCLAIMER

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

MODEL SIMPLIFICATION: A CASE STUDY OF END USE DEMAND MODELING IN THE TRANSPORTATION SECTOR

Andrew Ford
Economics Group, Los Alamos National Laboratory, Los Alamos, New Mexico 87545

ABSTRACT

This paper considers the design of a rather simple model of petroleum use by automobiles in the US economy. The model must be simple to allow it to function within a larger end use demand model under construction for use within the FOSSIL2 modeling system. The simple model has been designed so that its behavior under reasonable conditions will resemble the behavior of a much more complex model of the nation's transportation system. The complex model, known as ENTRANS, was constructed at Dartmouth College for the US Department of Transportation.

The "model simplification" approach described in this paper requires the analyst to summarize the behavioral response of the more complex model in a form that is readily mimicked by the simple model. The band of uncertainty in the relationships used in the simple model are determined through sensitivity testing of the more complex model. Problems inherent in the "model simplification" process are discussed in the concluding portion of the paper.

INTRODUCTION

This is the second in a series of three papers presented at this conference dealing with the DEMAND'81 energy use simulation model under development at Purdue University and the Los Alamos National Laboratory. DEMAND'81 is a national, end use, energy simulation model designed specifically for the FOSSIL2 modeling system used for policy studies at the US Department of Energy. The purpose, scope, and generic structures of DEMAND'81 are explained by George Backus in the first paper of the series(1). This paper explains why the residential transportation sector of DEMAND'81 was singled out for more detailed study. The purpose of the paper is to illustrate how one may construct a highly simplified model sector by mimicking the behavior of a much more complex model. By relying heavily on the behavior of a complex model of automobile use, one faces the question of how to evaluate the credibility of a complex model. One approach is to compare the price elasticity of demand inferred from the behavior of the complex model with price elasticities obtained in econometric models of energy use. This approach is discussed by Anthony Bopp in the third paper of the series(2).

THE DEMAND'81 ENERGY USE SIMULATION MODEL

DEMAND'81 is a System Dynamics model of the demand for energy in the residential, commercial, industrial, and transportation sectors of the United States economy. George Backus, the principal architect of the model, provides a brief description of the model in the first paper of this series(1). Figure 1 shows the way in which the demand for a particular type of fuel in a specific sector is calculated using the "generic assumptions" adopted by Backus. In this example, the demand for natural gas from substitutable end uses in the nation's residential sector is shown to depend on:

- the number of new residences choosing natural gas over competing fuels,
- the residences' average furnace efficiency,
- the overall efficiency of the average residence's "shell" in retaining the heat supplied by the gas furnace, and
- the temporary reductions in rooms heated due to budgetary restrictions on the average resident.

Figure 1 shows that each of these factors is, in turn, influenced by the price of natural gas delivered to the average

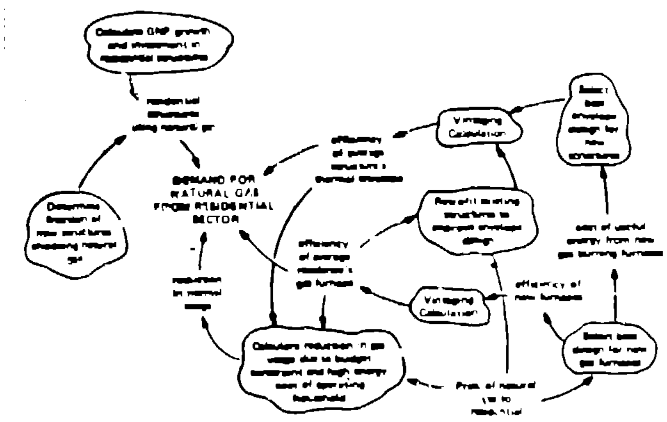

Figure 1.
Application of generic assumptions in DEMAND'81 to the calculation of the demand for natural gas in the residential sector.

residential customer. A fundamental assumption in the calculation of gas furnace efficiency and the overall efficiency of the house is that improved efficiencies are only obtained with investments in better equipment, and that the investment costs exhibit diminishing returns as the efficiencies come closer to the maximum possible efficiency. This generic assumption is used throughout the DEMAND'81 model with one important exception--the residential transportation sector.

The demand for petroleum for the nation's automobiles and light trucks cannot be treated using the generic investment cost assumptions applied elsewhere in DEMAND'81 because of the substantial improvements in automobile fuel efficiency through down sizing. Down sizing refers to the redesign of automobiles to achieve lower weight and higher fuel efficiency by reducing the car's exterior dimensions while retaining approximately the same internal space. According to a Federal Task Force study of automobile redesign, a combination of design changes could increase a five-passenger automobile fuel economy from 18.3 mpg to 30.7 mpg and lower the cost of the car from \$4400 to \$4300(3). Not only could particular models be redesigned to achieve a higher miles-per-gallon without higher costs, but consumers could alter the mix of cars purchased. A shift to smaller cars would improve the fleet's average fuel efficiency while lowering the sales-weighted average car cost.

Since down sizing is not easily represented with the generic cost assumptions used in DEMAND'81, some modification in the generic structures described by Backus(1) is required. Currently, research is directed toward the development of an extremely simple structure that will yield the same general behavior as a more complex model. For this "simplification" approach to work, the complex model must represent down sizing and auto mix shifts explicitly. At present, we are studying the possibility of building the residential transportation sector to mimic the behavior of the ENTRANS model of the nation's automobile and travel sectors.

THE ENTRANS MODEL

ENTRANS was developed by Adler(4), Ison(5), and Geinzer(6) at Dartmouth College for the US Department of Transportation. The behavior of ENTRANS during the historical period from 1950 to 1980 along with a "base case" projection to the year 2020 is shown in Fig. 2. The principal exogenous inputs to the model are the price of gasoline, the number of families, and total personal income. Growth in families and income is responsible for the steady rise in auto vehicle miles of travel in Fig. 2. New car fuel economy ranges from 12 to 13 mpg during the 1950s and 1960s, but the new car fleet miles-per-gallon rises during the 1970s and 1980s due to a combination of higher gas prices and federal regulations on the auto manufacturers. New fleet miles-per-gallon is shown to level off at around 22 mpg in 1985 (an "on the road equivalent of the federal regulation for a 27.5 mpg performance using the Environmental Protection Agency's composite city-highway dynamometer miles-per-gallon measurements). The average fuel economy of the cars in use is shown to lag behind the new car efficiency due to the delay in automobile turnover. During the period of improving automobile fuel efficiency, consumption of gasoline is projected to decline. Once the fleet-wide miles-per-gallon levels off at around 22, however, gasoline consumption increases over time due to the steady growth in vehicle miles of travel.

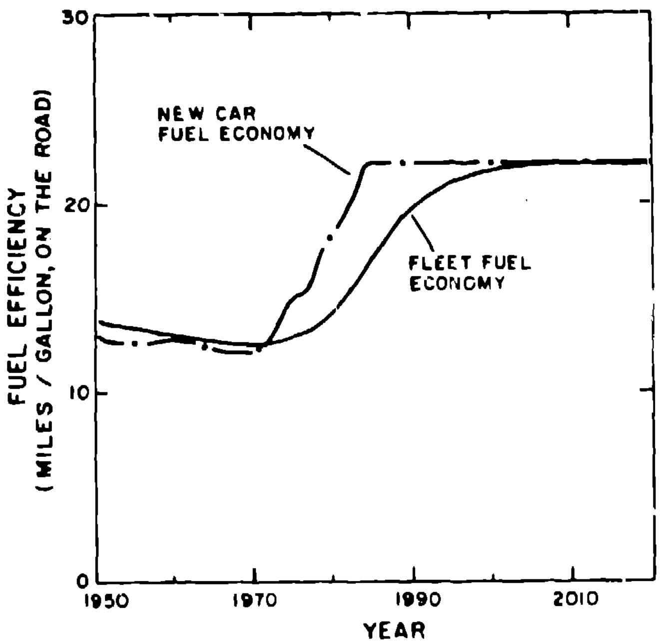

Figure 2A.
Illustrative example of ENTRANS behavior, fuel economy.

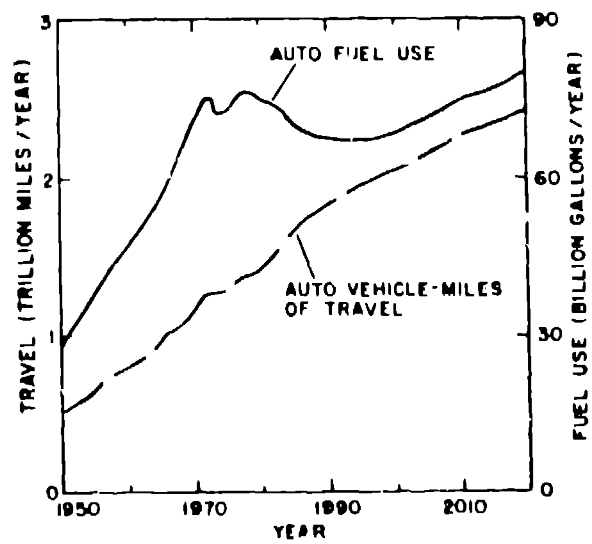

Figure 2B.
Illustrative example of ENTRANS behavior, travel and fuel use.

The automobile fuel efficiency shown in Fig. 2 is calculated by taking the sales-weighted harmonic mean of the fuel efficiencies of five classes of cars treated in the model. These include subcompact, compact, intermediate, full-sized, and luxury vehicles. Each car is characterized by a price, a fuel efficiency, an intrinsic utility, and a possible price penalty (or price reduction) should manufacturers adopt "differential pricing" in order to comply with Federal regulation on the new fleet efficiency. A model of consumer choice adapted from the multinomial regression model developed by Lave and Train(7) is used in ENTRANS to represent the likely mix of cars to be purchased in the future. Redesign of each of the five classes of cars is simulated through the use of cost curves representing the change in costs to obtain higher fuel efficiency. The model automatically moves to a better design for each of the five classes of cars if the cost of the design change can be paid back in the form of lower fuel costs over 50,000 miles of travel at the current cost of gasoline.

The vehicle miles of travel in Fig. 2 is the sum of the miles of local travel in and around the nation's cities, suburbs and towns and the miles of longer distance, intercity travel. The local travel sector is a complex model of the travel decisions of seven different income groups facing both a constraint on the amount of money that can be spent on fuel and incidental fees and a "time constraint" that limits the number of hours per day that can be spent behind the wheel. The intercity travel sector is a somewhat simpler sector in which only a money constraint is imposed to limit the number of intercity vehicle miles traveled by each of the seven income groups per year.

A useful summary of the behavioral tendencies of the ENTRANS model is given in Fig. 3, which displays the price elasticity of gasoline usage for the situation where price increases start from a base price of $1 per gallon or from $2 per gallon. Also shown in this diagram is the time required for a full response of the model to any price increase. The overall elasticity is broken down into the auto efficiency response (due to better miles-per-gallon) and to the travel response (fewer vehicle miles of travel).

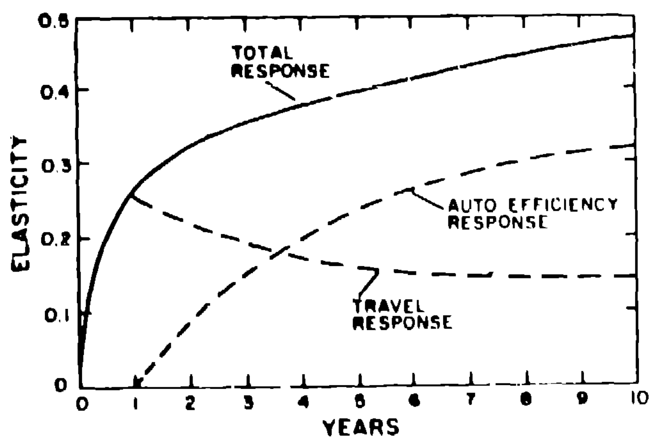

Figure 3A.
Summary of ENTRANS response to an increase in the price of gasoline from a base price of $1 per gallon (in 1975$).

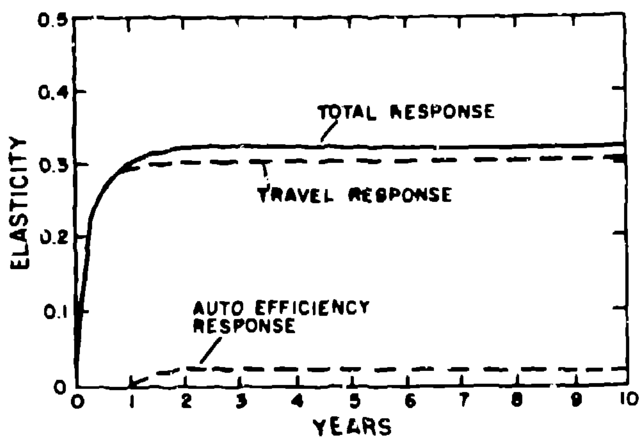

Figure 3B.
Summary of ENTRANS response to an increase in the price of gasoline from a base price of $2 per gallon (in 1975$).

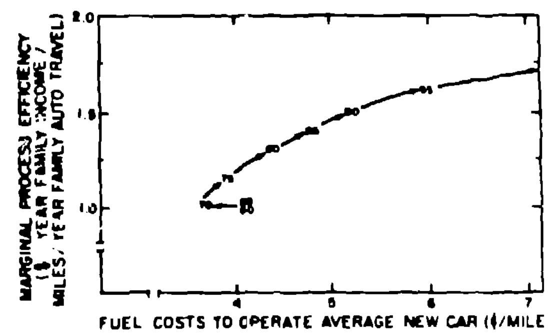

Figure 5.
ENTRANS projections of process efficiency versus new car fuel costs.

SIMPLIFICATION OF ENTRANS OUTPUT

If the residential transportation sector of the DEMAND'81 model is to behave in a fashion similar to ENTRANS, the output of ENTRANS must be arranged in such a way to allow easy duplication. Figure 4 shows how this might be done for the DEMAND'81 calculation of the new car fleet average fuel efficiency. In this diagram, results from particular years of an ENTRANS simulation are arranged depending on the price of gasoline in that year as well as the average fuel efficiency. Efficiency in Fig. 4 is expressed in terms of "on-the-road" performance and is calculated from the sales-weighted harmonic mean of the fuel efficiencies of the five classes of autos used in ENTRANS. The particular simulation results shown in Fig. 4 did not include the Federal regulations that require 27.5 mpg (EPA rating) by 1985, so the new car efficiencies shown in this diagram are lower than those shown in Fig. 2.

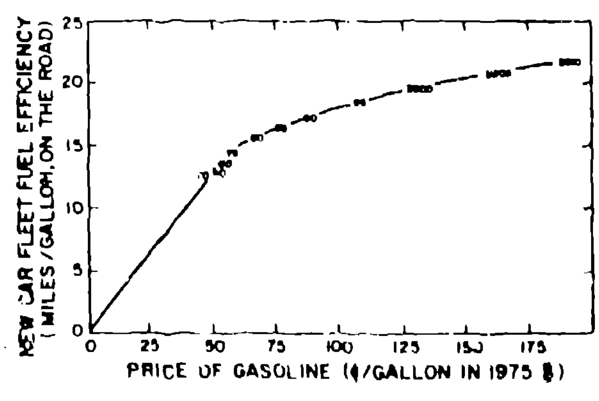

Figure 4.
ENTRANS projections of new car fuel efficiency versus the price of gasoline.

Figure 5 shows the efficiency curve that could be used in the residential transportation sector of DEMAND'81 if the model is to yield the same annual vehicle miles of travel as the more complicated ENTRANS model. This curve arranges ENTRANS results according to the fuel cost to operate a new car. These range from around 3.8 to 4 cents/mile in the 1970s and grow to about 6 cents/mile by the end of the century due to the higher price of gasoline. The vertical axis in Fig. 5 gives the marginal process efficiency. If this efficiency is set at 1.0, one may assume that a family with a combined annual income of $15,000 would require 15,000 vehicle miles during a year. Increases in this efficiency imply less need for travel for a family of a given income.

ADVANTAGES AND PROBLEMS WITH MODEL SIMPLIFICATION

The curves shown in Figs. 4 and 5 could be used to allow DEMAND'81 to exhibit the same general behavior as the ENTRANS model. With these curves, one would expect the simple residential transportation sector of DEMAND'81 to show the same results as ENTRANS provided both models are "driven" with the same values of the price of gasoline, growth in personal income, and growth in the number of households. When sensitivity testing is to be performed, the uncertain input parameters in the ENTRANS model would be altered, a new set of simulation results produced, and a new set of efficiency curves would be generated for use in DEMAND'81. The advantages of such a "model simplification" approach are threefold. First, the objective of maintaining a small sector to operate within a larger modeling system is achieved. Secondly, the residential transportation sector is simple enough to be easily understood by the model user. Thirdly, model simplification allows researchers to take advantage of the previous investment of time and effort (leading to the ENTRANS model) without attempting to incorporate the entire ENTRANS model itself in the FOSSIL2 system.

The model simplifcation approach is not trouble-free, however. Several problems arose in the research with ENTRANS. These problems are mentioned here to provide a concluding note of caution to other researchers considering the model simplification approach.

One problem is that the functions used to mimic the complex model may be double-valued. In Fig. 5, for example, there are two possible process efficiencies when the new car fuel cost is 4.25 cents/mile. One value, taken from the 1960s ENTRANS behavior, is about 1.0. Later, in the 1980s, however, the process efficiency is about 1.25. The appearance of a double valued function may indicate that explanatory variable is not the most suitable variable to use in mimicking the complex model. Selection of an alternative explanatory variable may lead to a single-valued function. (In the specific case of mimicking ENTRANS vehicle miles of travel, however, the new car auto fuel cost was found to be the best explanatory variable. Consequently, some adjustment is required to deal with the double-valued function in Fig. 5.)

A second problem with model simplification is mistaken causality. In the ENTRANS example, mistaken causality can occur in Fig. 5 if the researcher assumes that increases in the fuel cost are directly responsible for the increases in the process efficiency. An examination of ENTRANS behavior shows that the increase in process efficiency (reductions in vehicle miles of travel required for a family of a particular income) are not entirely due to higher costs of fuel. A substantial portion of the reduction in vehicle miles of travel are due to congestion of the nation's highway system, which limits the miles per day that many of the income groups in the ENTRANS intercity sector can travel without exceeding the maximum number of hours "behind the wheel." That is, the more affluent groups are driving less because of congestion and not because of the higher cost of gasoline. Mistaken causality can be a serious problem when it comes time to interpret the performance of a model like DEMAND'81. Careful interpretation requires one to understand both the simple model and the complex model whose behavior is being mimicked.

A third problem with model simplification is that one must establish the credibility of the complex model. This can be difficult if (as is often the case) the model developers were encouraged to invest their time in model construction and not model documentation. One particular test that could help researchers to evaluate the performance of a complex, energy-demand model, is to alter the price of the fuel and observe the overall response of the model after the price increase. In the case of the ENTRANS model, the response to increases in the price of gasoline is summarized in Fig. 3. It may be informative to compare the price elasticity measured in this fashion with the price elasticities obtained from interpreting the coefficients in regression analysis of the demand for gasoline. This approach to model evaluation is discussed in the third paper of this series by Anthony Bopp(2).

REFERENCES

1. George Backus, "Modeling the Causal Mechanisms of Energy Demand," 1981 Summer Computer Simulation Conference (this volume), July, 1981.

2. Anthony E. Bopp, "Model Evaluation Through Elasticity Comparisons: A Case Study of End Use Demand Modeling in the Transportation Sector," 1981 Summer Computer Simulation Conference (this volume), July, 1981.

3. Department of Transportation, The Report by the Federal Task Force on Motor Vehicle Goals Beyond 1980, Volume 2, September 1976, pg. 13-3.

4. Thomas Adler, John Ison, and Jay Geinzer, "Interactions Between Energy Supply and Transportation-Related Energy Use," Resource Policy Center, Dartmouth College, Hanover, New Hampshire, report DSD 182, January 1980.

5. John Ison, "The Effect of Government Policy on Future Automobile Fuel Economy," Resource Policy Center, Dartmouth College, Hanover, New Hampshire, report DSD 203, January 1980.

6. Jay Geinzer, "Travel in an Energy-Constrained Future," Resource Policy Center, Dartmouth College, Hanover, New Hampshire, report DSD 200, November 1979.

7. Charles Lave and Kenneth Train, "A Disaggregate Model of Auto-Type Choice," Transportation Research, Vol. 13, No. 1, pp. 1-9, 1979.